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L-SHELL RESONANT TRANSFER AND EXCITATION FOR NE-LIKE NIOBIUM IONS

E. M. BERNSTEIN*, M. W. CLARK*, J. A. TANIS*, W. G. GRAHAM#, R. H. McFARLAND∫, J. R. MOWAT∆, D. W. MUELLER ξ, M. P. STOCKLI ε, K. H. BERKNER+, R. J. McDONALD+, A. S. SCHLACHTER+, AND J. W. STEARNS+

* Dept. of Physics, Western Michigan University, Kalamazoo, Michigan USA

Physics Dept., University of Ulster, Coleraine, Northern Ireland

∫ Dept. of Physics, University of Missouri, Rolla, Missouri USA

∆ Dept. of Physics, North Carolina State University, Raleigh, N.C. USA

ξ Dept. of Physics, Louisiana State University, Baton Rouge, Louisiana USA

ε Dept. of Physics, Kansas State University, Manhattan, Kansas USA

\+ Lawrence Berkeley Laboratory, Berkeley, California USA

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1. Introduction

Recent experimental studies[1,2] have shown that projectile excitation and charge transfer (capture) can occur simultaneously in a single encounter with a target atom through the electron-electron interaction between a projectile electron and a (weakly bound) target electron. This process is referred to as resonant transfer and excitation (RTE). The intermediate excited state which is formed in the RTE process can subsequently decay by photon emission or electron emission (Auger decay). RTE is analogous to dielectronic recombination[3] (DR), in which the captured electron is initially free instead of bound. RTE and DR proceed via the inverse of an Auger transition and, hence, are resonant for projectile velocities (in the rest frame of the electron) corresponding to allowed Auger electron energies.

RTE has been identified experimentally for K-shell excitations by the observation of resonant behavior in the energy dependence of (1) the yield of deexcitation photons coincident with projectiles which have captured an electron, and (2) the yield of Auger electron emission associated with capture events.[4] Previous experiments with H_2 and He targets have also established the dependences of the cross sections for K-shell RTE on the projectile atomic number[5] and charge state.[6] The existing K-shell RTE data are in reasonable agreement with calculated RTE cross sections based on theoretical[7] DR cross sections, indicating a close link between RTE and dielectronic recombination.

Additional information concerning the RTE process and its relationship to DR is expected to be obtained from studies of RTE involving excitation of the projectile L-shell. Currently very few data exist for L-shell RTE. Resonant behavior for L x-ray emission coincident with projectile electron capture was observed[8] for 455-710 MeV $_{57}La^{40+}$ ions incident on H_2. While there are presently no detailed theoretical calculations to compare with these results, the energy position of the maximum in the observed coincidence cross section is consistent with that expected on the basis of specific Auger transitions. In another experiment measurements[9] were made of the total Lα x-ray production without coincidence requirements for a range of charge states for 3.6 MeV/u Sm^{q+} + Xe collisions. A maximum was observed in the x-ray emission cross section for charge states with $46 \leq q \leq 52$. This maximum was attributed to L-shell RTE, and was found to be consistent with RTE calculations.

In the present work we have investigated L-shell RTE for 230-610 MeV Nb^{31+} (neonlike) ions incident on H_2. The closed L-shell configuration for the projectile was chosen to simplify the theoretical analysis in order to facilitate a comparision between experiment and theory.[10]

2. Experimental procedure

The measurements reported here were obtained at the Lawrence Berkeley Laboratory using the SuperHILAC. Briefly, the experimental technique consisted of measuring projectile L x rays coincident with single-electron-capture events, following the passage of Nb^{31+} ions through a differentially pumped gas cell. L x rays produced in collisions with the H_2 target gas were detected with a Si(Li) detector mounted at 90° to the beam axis. The beam, after emerging from the gas cell, was magnetically analyzed into its charge-state components. Ions undergoing electron capture in the target gas were detected with a solid-state detector. The non-charge-changed component of the emerging beam was collected in a Faraday cup. Coincidences between L x rays and projectile ions capturing an electron were measured using a time-to-amplitude converter. The x-ray and coincidence yields were measured as a function of gas pressure to obtain the desired cross sections and to ensure that single-collision conditions prevailed. A capacitance manometer was used to measure the absolute pressure in the target gas cell.

3. Results and Discussion

The measured cross sections, $\sigma^{q-1}_{L\alpha\beta}$, for projectile Lαβ x-ray emission coincident with single electron capture are shown in Fig. 1. Relative uncertainties in the data points are indicated by the error bars. The overall uncertainty in the absolute cross sections is about ± 20%. The pronounced maximum in $\sigma^{q-1}_{L\alpha\beta}$ near 335 MeV is attributed to RTE involving L-shell excitation of ${}_{41}Nb^{31+}$. The cross section at the RTE peak is an order of magnitude larger than the largest peak values observed to date for K-shell RTE.

The vertical lines shown on the energy scale in Fig. 1 indicate the positions of the strongest Auger transitions in Nb^{30+} involving 2p excitations. The lines are labeled with the configurations of the excited and captured electrons in the intermediate states in the RTE process. Those states with n>6 are grouped together at 404 MeV. The height of each line is proportional to the theoretical DR cross section for the particular intermediate state or group of states. These cross sections, obtained from a preliminary calculation by Hahn et al.,[11] are expected to be accurate to ±10%. While 2p excitations dominate, additional contributions to L-shell RTE in the energy region between 260 and 410 MeV will be produced by excitation of the projectile 2s electrons.

As expected for RTE the observed maximum in $\sigma^{q-1}_{L\alpha\beta}$ occurs at energies corresponding to strong Auger transitions. We have calculated the theoretical RTE cross section based on the calculated[11] DR cross sections with the 2s excitation included.[11] This calculated RTE cross section (normalized by a factor of 0.75) is shown as the solid line in Fig. 1. The agreement between theory and experiment is reasonable, although the theory overestimates the measurements by about 25% near the RTE maximum. More accurate measurements are needed in order to ascertain the existence of the structure seen in the calculated curve. However, it should be noted that the dip in the calculated curve may arise, at least in part, as an artifact of the present calculation since the DR cross section from a group of nearby states is concentrated at a single mean energy. Thus, more detailed calculations of the energies and DR cross sections for individual states should be made. At the higher energies the theory falls more rapidly than the data. This difference between experiment and theory is similar to previous results obtained for K-shell RTE.[5]

We would like to point out that another strong resonant structure due to L-shell RTE for Nb^{31+} is expected near 160 MeV. This is the energy region corresponding to the formation of intermediate states where both the excited and captured electron have n=3. Unfortunately, we were not able to investigate this region since a Nb^{31+} beam was not available at those lower energies.

In conclusion, L-shell resonant transfer and excitation has been observed for neonlike niobium. While the data are in reasonable agreement with theory, additional experimental and theoretical work is necessary to resolve some discrepancies. The measured L-shell RTE cross section is an order of magnitude larger than the largest K-shell RTE cross section observed to date.

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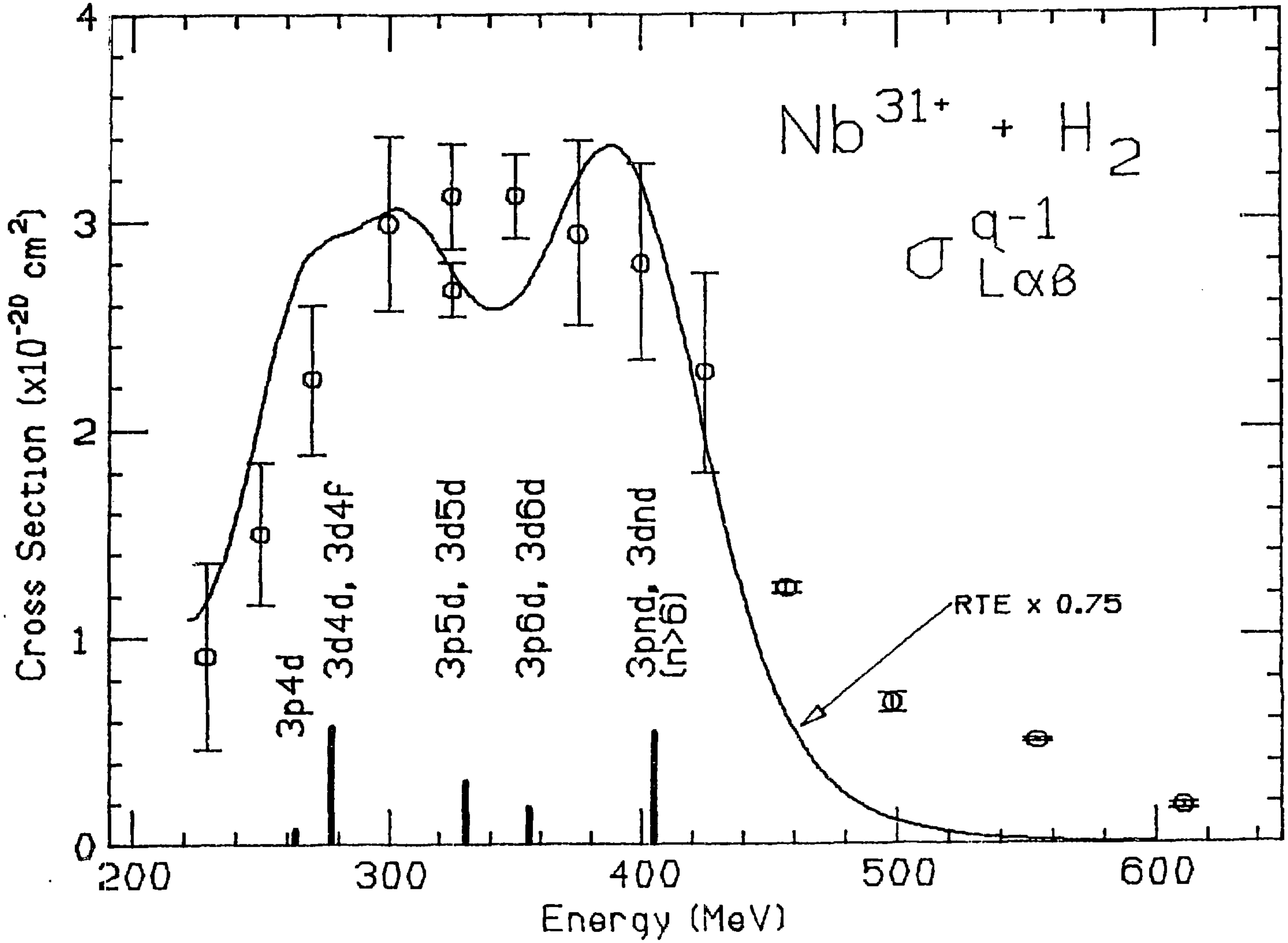
REFERENCES

1. J. A. Tanis, E. M. Bernstein, W. G. Graham, M. Clark, S. M. Shafroth, B. M. Johnson, K. W. Jones, and M. Meron, Phys. Rev. Lett. 49, 1325 (1982).
2. J. A. Tanis, E. M. Bernstein, W. G. Graham, M. P. Stockli, M. Clark, R. H. McFarland, T. J. Morgan, K. H. Berkner, A. S. Schlachter, and J. W. Stearns, Phys. Rev. Lett. 53, 2551 (1984).
3. A. Burgess, Astrophys. J. 139, 776 (1964); 141, 1588 (1965).
4. J. K. Swenson, N. Stolterfoht, Y. Yamasaki, P. D. Miller, H. Krause, P. F. Dittner, P. L. Pepmiller, and S. Datz, Proceedings of the II US-Mexico Symposium on Atomic and Molecular Physics, Cocoyoc, Mexico, 1986, to be published.
5. J. A. Tanis, E. M. Bernstein, C. S. Oglesby, W. G. Graham, M. Clark, R. H. McFarland, T. J. Morgan, M. P. Stockli, K. H. Berkner, A. S. Schlachter, J. W. Stearns, B. M. Johnson, K. W. Jones, and M. Meron, Nucl. Instr. Meth. B10/11, 128 (1985).
6. J. A. Tanis, E. M. Bernstein, M. W. Clark, W. G. Graham, R. H. McFarland, T. J. Morgan, J. R. Mowat, D. W. Mueller, A. Muller, M. P. Stockli, K. H. Berkner, P. Gohil, R. J. McDonald, A. S. Schlachter, and J. W. Stearns, Phys. Rev. A 34, 2543 (1986).
7. D. J. McLaughin and Y. Hahn, Phys. Lett. 88A, 394 (1982); I. Nasser and Y. Hahn, J. Quant. Spectrosc. Radiat. Transfer 29, 1 (1983); D. J. McLaughlin and Y. Hahn, Phys. Lett. 112A, 389 (1985).
8. M. W. Clark, E. M. Bernstein, J. A. Tanis, K. H. Berkner, P. Gohil, W. G. Graham, R. H. McFarland, T. J. Morgan, A. Muller, A. S. Schlachter, J. W. Stearns, and M. P. Stockli, XIVth International Conference on the Physics of Electronic and Atomic Collisions, Palo Alto, California, 1985, Abstracts of Contributed Papers, p. 393.
9. W. A. Schonfeldt, P. H. Mokler, D. H. H. Hoffmann, and A. Warczek, Z. Phys. A 321, 693 (1985).
10. Y. Hahn, private communication.
11. Y. Hahn, J. N. Gau, and M. P. Dube, to be published.

FIGURE CAPTION

Fig. 1 Cross sections for projectile L-shell x rays coincident with single-electron capture, $\sigma^{q-1}_{L\alpha\beta}$, for collisions of $_{41}Nb^{31+}$ with H_2. The vertical lines give the theoretical positions and relative intensities of the strongest Auger transitions involving 2p excitations. The configurations of the excited and captured electrons in the intermediate state are indicated. The solid curve is a theoretical RTE calculation based on the DR cross section calculations from Ref. 11 (see text).



Nb31+ + H2
σ q-1 Lαβ
Cross Section (x10-20 cm2)
Energy (MeV)
3p4d
3d4d, 3d4f
3p5d, 3d5d
3p6d, 3d6d
3pnd, 3dnd (n>6)
RTE x 0.75
0
1
2
3
4
200
300
400
500
600